International Journal of Engineering & Technology, 7 (4.20) (2018) 59-66

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Nominal Aggregate Size an Index to The Resilient Modulus Value of Hot Mix Asphalt

Sahar S. Neham

Al-Furat Al-Awsat Technical University, Kerbalaa Technical Institute
** Corresponding author E-mail: Naham_1969@yahoo.com*

Abstract

Properties and performance of hot mix asphalt are highly affected by aggregate as it is consists of 85 to 95 percent by weight and 75 to 85 percent by volume mineral aggregate. Resilient modulus was a very important parameter used either as input data in the procedure of pavement design or to evaluate the relative quality of materials. This research study the effect of nominal aggregate size on the resilient modulus value with different variations such as tested temperature, percent of asphalt cement and filler content, load duration, and asphalt viscosity. Results under different variables showed that nominal aggregate size has a significant effect on the resilient modulus value as well as resilient modulus value decreases by (21.04% - 26.66%) when the nominal aggregate size increases from 19mm to 25mm while it decreases by (22.43 - 29.50%) when the nominal aggregate size increases from 25mm to 37.3mm.

Keywords: *ASTM D1234, Hot Mix Asphalt, nominal aggregate size, resilient modulus.*

1. Introduction

The main objective of this study: evaluating the hot mix asphalt resilient modulus value effected by nominal aggregate size, a number of researchers deals with several factors that affect the resilient modulus testing, such as pavement temperature, test temperature, loading effect, aggregate properties, binder content, specimen dimension and compaction methods.
[1] recognized that coarse aggregate morphological properties could be related to the stiffness of asphalt mixes. In fact, the relationship is not comprehensible due to the lack of quantitative measurements of coarse aggregate morphology. As well as some of the aggregate structure, properties influence the resilient modulus of asphalt mixes such as aggregate gradation and nominal maximum size.
[2] conducted that there is good correlation between the resilient modulus and the maximum aggregate size. If the aggregate size increases, the resilient modulus increases too.
[3] suggested the relationship of the diameter/maximum nominal stone size ratio with the resilient modulus; the resilient modulus decreases as the ratio increases.
[4] reported that decreasing the nominal aggregate size from 19mm to 9.5mm indicated an improvement on the resilient modulus of asphalt mixes according to aggregate morphology.
[5] referred that the resilient modulus test data when grouped according to asphalt binder grade and stiffness typically demonstrated a much higher agreement to the coarse aggregate morphology than the un _grouped data. According to the observations made and through the restricted zone (BRZ and TRZ) gradation groups, the gradation of aggregate structure showed contradicting effects on the relationship between the coarse aggregate morphology and the resilient modulus of asphalt mixes. The nominal maximum aggregate size did not consistently influence the contribution of the coarse aggregate morphology to the resilient modulus; a decrease in the nominal maximum aggregate size from 19mm to 9.5mm typically indicated an increasing positive influence of aggregate morphology on the resilient modulus of asphalt mixes.
[6] explained that the values of resilient modulus are also influenced by the flaky aggregate content; the values of resilient modulus decrease with increasing the flaky aggregate content.
[7] concluded that the coarse gradation causes decreased resilient strain by 91% for a nominal maximum aggregate size of 19 mm.
[8] proved the effect of the maximum nominal aggregate size on resilient modulus. It is clear that the coarser the aggregate gradations, the higher the resilient modulus of the asphalt mix. This is expected because of the fact that larger aggregates have higher particle-to-particle contact with the coarser aggregate structure.

2. Materials

Materials, including three types of asphalt cement grades, were prepared and considered at AC 20-30, 40-50 and 60-70; three types of aggregate gradation were considered as nominal size 37.5mm (1½ inch), 25mm (1 inch) and 19mm (¾ inch) and one type of mineral filler.

2.1 Asphalt Cement Characteristics

Three types of asphalt cement were employed from AL Daurah refinery, including (20 - 30), (40-50) and (60-70) penetration graded. The physical properties of these are presented in Table1.

2.2 Aggregate Properties

The aggregate used in laboratory work was local aggregate crushed from the Al - Ekheder quarry. Table 2 presented the aggregate gradations used to prepare material of mix for wearing courses

which is the nominal aggregate size of 19mm (¾ inch), at filler content (5%, 7% and 9%), leveling courses which is the nominal aggregate size of 25mm (1 inch), at filler content (4%, 6% and 8%) and base courses which is the nominal aggregate size of 37.5mm (1½ inch), at filler content (3%, 5% and 7%) depending on the allowed limits of the Iraqi Specification Limits (2003,R9) .
Table 2 presented the Selected Gradations for asphalt concrete mixtures according to the dependent specification, also Table 3 explained the Physical Properties of coarse and fine aggregates.

2 3 Mineral Filler

The filler material used was a limestone dust. It is non - plastic filler produced in the lime factory in Karbala governorate. The physical properties of the filler used are shown in Table 4.

3. Mixture Design

To accomplish the requirement of the research, Marshall Criteria was used to design the asphalt mixtures to determine the optimum asphalt content. Figure 1 represents the specimens prepared to obtain the optimum asphalt content to each nominal aggregate size. Table 5 summarizes the result of the marshal design method for all nominal aggregate size with three types of used asphalt to determine the optimum asphalt content.

Table 1: Physical Properties of Asphalt Cement

Test	Test Condition	ASTM, Designation	Units	Binder			SCRB Criteria *		
				20-30	40-50	60-70			
Penetration	100 gm, 25 °C, 5 Sec., 0.1 mm	D5	1/10 mm	24. 26	47.17	66.38	20-30	40-50	60-70
Rotational Viscosity	135°C	D4402	Pa.S.	0.584	0.478	0.351	----	----	----
	165 °C			0.171	0.136	0.122	----	----	----
Specific Gravity	25 °C	D70	----	1.046	1.031	1.024	----	----	----
Ductility	25 °C, 5 cm/min	D113	Cm	>150	>150	>150	----	>100	>100
Flash Point	----	D92	°C	329	302	292	>232	>232	>232
Softening Point	----	D36	°C	44	41	40	----	----	----
Solubility in trichloroethylene	----	D2042	% wt.	99.2	99.4	99.5	> 99	> 99	> 99
% Loss After Thin Film Oven Test	5 hr at 163 °C, 50 gm	D1754	% wt.	0.10	0.09	0.17	< 0.75	< 0.75	< 0.75
% From Origin Penetration After Thin Film oven Test	100 gm, 25 °C, 5 Sec., 0.1 mm	D5	%	90.06	57.5	54.21	----	>55%	>52%
Ductility After Thin Film Oven Test	25 °C, 5 cm/min	D113	Cm	>150	>150	>150	----	> 25	> 50

SCRB Criteria *: State Corporation for Roads and Bridges (R9), (2003);
Tested in the laboratory of Kerbela University.

Table 2: Selected Gradations for Asphalt Concrete Mixtures with Iraqi Specification Limits(SCRB 2003,R9)

Sieve Size		Percent Passing (%)/ Nominal Aggregate Size								
Sieve No.	Sieve Opening mm	19mm (¾ inch)			25mm1(inch)			37.5mm1(½inch)		
		P200, %			P200, %			P200, %		
		5	7	9	4	6	8	3	5	7
1 ½ in	37.5	----	----	----	----	----	----	100	100	100
1 in	25	----	----	----	100	100	100	94.9	95	95.1
¾ in	19	100	100	100	94.9	95	95.2	82.7	83	83.3
½ in	12.5	94.9	95	95.2	79.6	80	80.5	67.4	68	68.6
3/8 in	9.5	82.6	83	83.4	67.3	68	68.7	60.2	61	61.7
No. 4	4.75	58.1	59	59.9	48.9	50	51.1	42.9	44	45.1
No. 8	2.36	41.8	43	44.3	34.6	36	37.4	30.6	32	33.4
N0.50	0.3	11.2	13	14.9	10.1	12	13.9	9.1	11	12.9
No. 200	0.075	5	7	9	4	6	8	3	5	7

Table 3: Summery of Physical Properties of Aggregate

Property	ASTEM Test No.	Coarse Aggregate	Fine Aggregate	Superpave Specification
Bulk Specific Gravity	C - 127 & C - 128	2.57	2.67	-----
Apparent Specific Gravity	C - 127 & C - 128	2.65	2.74	-----
Percent of Water Absorption	C - 127 & C - 128	1.30%	3.62 %	-----
% of Wear Abrasion (Loss Angeles)	C – 131	17.67%	-----	35 - 45
Soundness Loss by Sodium Sulfate Solution %	C – 88	2.10%	5.59	10 - 20
Fractured Pieces	----	96	----	95 Min.
Deleterious Materials%	C -142	0.36	2.8	0.2 – 10
Sand Equivalent%	D – 2419	-----	57	45 Min.

*: Physical aggregate properties tested in the laboratory of Kerbela technical instituted

Table 4: *Physical Properties of Mineral Filler

Property	Test Result**
Specific Gravity	2.73
Passing Sieve No.200 (0.075 ^{mm})	93
Specific Surface (m^2/kg)	244

*: Physical mineral filler properties tested in the laboratory of Kerbela technical instituted
**: The result identical with the AASHTO m216- 2005 specification.

Table 5: Summary of Determined Optimum AsphaltContent According to Marshall Mix Design Criteria

Nominal Aggregate Size	Asphalt Cement Type	Optimum Asphalt Content at			Average Optimum Asphalt Content,%
		Max. Stability, Kn	Max. Unite Weight, gm/cm^3	$4^{\%}$ Air Voids, %	
¾ in	60-70	4.79	4.71	4.58	4.7
	40-50	4.68	4.87	4.85	4.8
	20-30	4.95	4.78	4.9	4.9
1 in	60-70	4.84	4.62	4.36	4.6
	40-50	4.71	4.82	4.58	4.7
	20-30	4.72	4.73	4.95	4.8
1 ½ in	60-70	4.07	4.02	4.2	4.1
	40-50	4.23	4.25	4.09	4.2
	20-30	4.28	4.25	4.35	4.3

Fig.1: Specimens Prepare to Obtain the Optimum Asphalt Content to Each Nominal Aggregate Size

4. Specimens Preparation

To prepare the specimens aggregate was heated to 170 °C and the range of heated asphalt cement temperature was between 150°C - 165°C to prepare 27by2 mix to each nominal aggregate size (54 specimens for ¾ inch at filler content (5%,7% and 9%), 54 specimens for 1 inch at filler content (4%,6% and 8%) and 54 specimens for 1 ½ inch at filler content (3%,5%and 7%) using the optimum asphalt content from Table (3-5) and ± 0.5 to this optimum for each nominal aggregate size and each binder type and compacted 75 blows / face according to Marshall design criteria with specimens dimension 101.6mm (4inch) in diameter and 63.5mm (2.5inch) in thickness . Figure 2 illustrates the specimens prepared, Table 6 presents the volume-etric properties of specimens prepared.

Fig. 2: Specimens Prepared for All Nominal Aggregate Size

5. Specimens Testing

To test resilient modulus of the prepared specimens using the procedure outlined in (ASTM D4123,1982). This test method covers procedures for preparing and testing laboratory-fabricated or field-recovered cores of bituminous mixtures to determine resilient modulus values using the nondestructive repeated-load indirect tension test. The procedure described covers a range of temperatures, loads, loading frequencies, and load durations. The recommended test series consists of testing at (5°C - 40°C) at one or more loading frequencies.
The five pulse indirect tensile modulus test is a substance stiffness test corresponding to ASTM D 4123,1982. In the test, a pulsed diameter loading force is applied to a specimen and the resulting total recoverable diameter strain is then measured from axes 90 degrees from the applied force. Strain in the same axes is not measured, thus a value of 0.35 for Poisson's ratio is used as a constant.
To achieve the requirements of the research, each specimen was tested in nine tests at 10°C, 25°C and 45 °C to each load duration 50 ms, 100 ms and 200 ms. Pulse width is related to the time of loading in actual pavements under the vehicle loads. To replicate the loading of faster moving vehicles, pulse width of value 50ms is selected and of value 200ms is selected for slower moving vehicles. Figure 3 explains the procedure of storing in nylon and wood box (using nine wood boxes, 18 specimens in each box at two layers to be carried by airplane).

Figure 4 explains the sample of input data of specimen according to ASTM D 4123, 1982 criteria; the condition of the test is:
Assumed Poisson’s Ratio 0.35;
Peak loading force 450N;
All specimens were left in the chamber for 3 hours to reach the stable temperature.
Each specimen loaded for 50 cycles, the first 45 are called conditioning pulses and recording and calculation of the MR is based on the next 5 pulse ie pulse No. from 46 to 50.
The loading was Haversine according to the standard and the loading time was 5%, 10% and 20% at 1 Hz frequency. This means the first case is loaded for 50 milliseconds loading and 950 millisecond rest, the second case is loaded for100ms loading and 900ms rest and the end case was 200ms loading time and 800ms rest.
The conditioning pulse count is limited to 1000 pulses.

6. Effect of Nominal Aggregate Size on Resilient Modulus

Three nominal aggregate sizes were used in this research: 19mm, 25mm, and 37.5mm. The average value of resilient modulus versus increase nominal aggregate size is calculated and presented in Table 7. These averages are shown graphically in Figure 5 which shows the effect of the nominal aggregate size of the resilient modulus for the three types of penetration grade of asphalt cement. Table 8 shows percent different of resilient modulus for each nominal aggregate size. The result shows that when increasing nominal aggregate size, resilient modulus decreases. This may be due to finer aggregate having more particle to particle interlock.

Table 6: Volumetric Properties of Specimens Prepared*

Nominal Aggregate Size	F.C%	Average %											
		ACT 60-70				ACT 40-50				ACT 20-30			
		O.A.C ± 0.5	AV	VMA	VFA	O.A.C ± 0.5	AV	VMA	VFA	O.A.C ± 0.5	AV	VMA	VFA
19mm ¾ in	5	4.2	4.12	20.23	79.63	4.3	4.61	20.92	77.96	4.4	4.84	22.81	78.78
		4.7	3.96	21.74	81.78	4.8	4.43	22.31	80.14	4.9	4.62	24.43	81.09
		5.2	3.90	21.91	82.20	5.3	4.22	23.10	81.73	5.4	4.43	26.51	83.29
	7	4.2	3.89	21.37	81.80	4.3	4.40	21.94	79.95	4.4	4.61	23.93	80.74
		4.7	3.74	21.91	82.93	4.8	4.11	23.51	82.52	4.9	4.44	26.52	83.26
		5.2	3.58	22.36	83.99	5.3	3.86	24.22	84.06	5.4	4.41	27.49	83.96
	9	4.2	3.80	21.83	82.59	4.3	4.09	23.38	82.51	4.4	4.50	24.86	81.90
		4.7	3.50	22.74	84.61	4.8	3.88	24.07	83.88	4.9	4.40	27.37	83.92
		5.2	3.45	22.96	84.97	5.3	3.71	24.52	84.87	5.4	4.37	28.03	84.41
25mm 1 in	4	4.1	4.42	16.53	73.26	4.2	4.73	17.81	73.44	4.3	4.91	19.30	74.56
		4.6	4.34	18.84	76.96	4.7	4.59	18.94	75.77	4.8	4.81	20.23	76.22
		5.1	4.01	20.71	80.64	5.2	4.32	21.02	79.45	5.3	4.58	23.41	80.44
	6	4.1	4.22	18.89	77.66	4.2	4.52	18.92	76.11	4.3	4.72	20.61	77.10
		4.6	4.18	20.84	79.94	4.7	4.44	21.17	79.03	4.8	4.57	22.05	79.27
		5.1	3.96	21.19	81.31	5.2	4.21	22.76	81.50	5.3	4.45	25.18	82.33
	8	4.1	4.00	19.10	79.06	4.2	4.35	20.36	78.63	4.3	4.51	21.73	79.25
		4.6	3.82	22.28	82.85	4.7	4.16	22.41	81.44	4.8	4.42	23.67	81.33
		5.1	3.91	23.74	83.53	5.2	3.95	25.79	84.68	5.3	4.39	26.38	83.36
37.5mm 1 ½ in	3	3.6	4.94	17.83	72.29	3.7	5.36	19.33	72.27	3.8	5.68	19.83	71.36
		4.1	4.86	19.32	74.84	4.2	5.15	20.73	75.16	4.3	5.41	22.84	76.31
		4.6	4.51	22.54	79.99	4.7	4.87	24.41	80.05	4.8	5.13	24.81	79.32
	5	3.6	4.82	18.41	73.82	3.7	5.26	20.31	74.10	3.8	5.52	21.98	74.89
		4.1	4.50	22.31	79.83	4.2	4.91	23.02	78.67	4.3	5.24	23.72	77.91
		4.6	4.28	23.03	81.42	4.7	4.70	25.11	81.28	4.8	5.06	26.95	81.22
	7	3.6	4.71	20.86	77.42	3.7	5.02	21.92	77.10	3.8	5.37	23.09	76.74
		4.1	4.32	23.88	81.91	4.2	4.76	24.76	80.78	4.3	5.01	27.21	81.59
		4.6	4.09	24.40	83.24	4.7	4.54	26.84	83.08	4.8	4.88	28.03	82.59

*: The specimens were tested on laboratory of Kerbela University; ACT: Asphalt cement type; F. C: Filler content;
O.A.C: Optimum Asphalt Content; AV: Average air voids; VMA: Void in mineral aggregates; and VFA: Voids field with asphalt.

Fig. 3: Procedure of Storing Specimens in Nylon and Wood Box. All tests took place in Civil and Environmental Engineering Department of AmirKabir University of Technology, in the Islamic Republic of Iran.

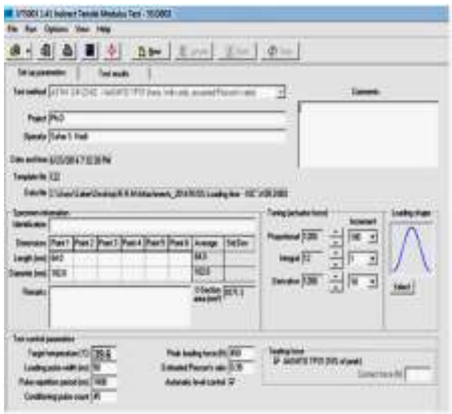

Fig. 4: View of Sample Input Data of Specimen By UTM – 25 According to ASTM D4123,1982

Table 7: Average Values of Resilient Modulus MPa with Increase Nominal Aggregate Size

Nominal Aggregate Size, mm	Average M_R MPa		
	60-70	40-50	20-30
19 (¾ in)	4713.14	6067.26	7610.24
25(1 in)	3787.6	4676.4	5801.3
37.5 (1 ½ in)	2937.88	3471.40	4089.84

M_R: Resilient modulus, MP

7. Resilient modulus value affected by percent asphalt content for each nominal aggregate size

The average value of resilient modulus is calculated and presented in Table 9 versus increase in percent of the asphalt cement content of 19mm (¾ in), 25mm(1 in) and 37.5mm (1 ½ in) nominal aggregate size with asphalt cement type 60-70, 40-50 and 20-30. Also Table 10 explains the percentage difference of Resilient Modulus due to increase asphalt cement content for each nominal aggregate size.

Table 8: Percent Different of Resilient Modulus Due to Increase Nominal Aggregate Size

Nominal Aggregate Size Increase mm		Percent Different in Resilient Modulus%		
From	To	60-70	40-50	20-30
19	25	19.64*	22.92	23.77
25	37.5	22.43	25.77	29.50
Average Percent Different in Resilient Modulus to Each A.C.T%		21.04	24.35	26.66

*: Example: $\% \, Diff.in\, MR = \left(\frac{MR@19mm-MR@\frac{25mm}{MR}@19mm}{MR@19mm}\right)*100$

$$\% \, Diff.in\, MR = \left(\frac{4713.14-3787.6}{4713.14}\right)*100 = 19.64\%$$

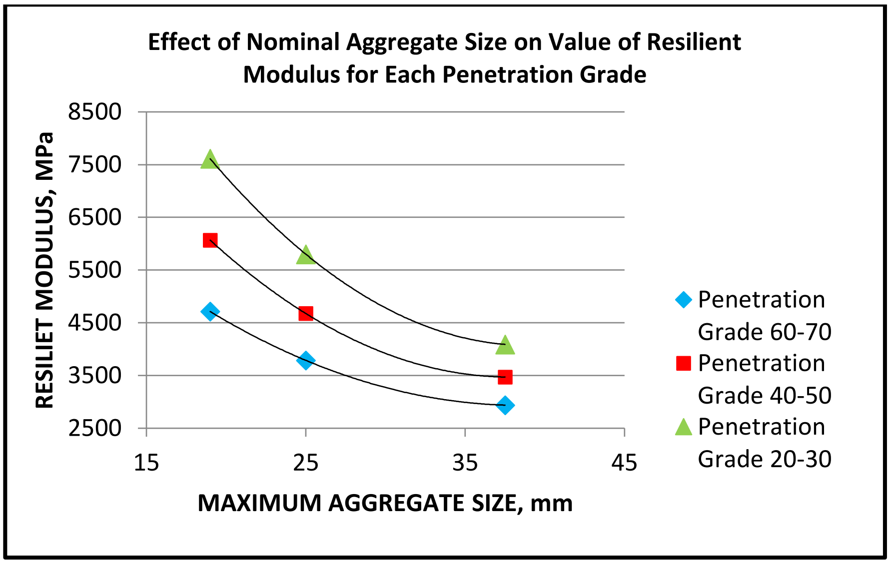

Fig. 5: Effect of Nominal Aggregate Size on Resilient Modulus (Average value) for to Each Penetration Grade

Table 9: Average Values of Resilient Modulus, MPa with Increase Percent of Asphalt Content for Each Nominal Aggregate Size

ACT	N.A.S 19mm		N.A.S 25mm		N.A.S 37.5mm	
	AC %	Average M_RMPa	AC %	Average M_RMPa	AC%	Average M_RMPa
60-70	4.2	4249.52	4.1	3328.07	3.6	2724.67
	4.7	4674.22	4.6	3563.33	4.1	2921.33
	5.2	5215.67	5.1	3871.33	4.6	3167.63
40-50	4.3	5471.11	4.2	4170.93	3.7	3162.63
	4.8	6094.85	4.7	4443.30	4.2	3457.19
	5.3	6635.86	5.2	4814.85	4.7	3794.37
20-30	4.4	6960.19	4.3	5126.63	3.8	3834.44
	4.9	7458.52	4.8	5613.22	4.3	4064.33
	5.4	8412.00	5.3	6063.89	4.8	4370.74

ACT: Asphalt cement type; N.A.S: Nominal aggregate size; AC%: Percent of asphalt cement content and M_R: Resilient modulus, MPa.

Table 9 shows that: the increase in percent of asphalt cement content leads to increasing the resilient modulus; when the asphalt cement content increases, adhesion of the inter-aggregate will improve and cause the recoverable strain to decrease so the resilient modulus increases.

8. Average Values of Resilient Modulus, MPa with Increase Percent of Filler for Each Nominal Aggregate Size

Three values of filler content Percent were used in this study to each nominal aggregate size. The average value of resilient modulus versus an increase in percent filler content is calculated and presented in Table 11. Table 12 explains the percentage difference of Resilient Modulus due to increase filler content for each nominal aggregate size.

Table 11 shows that: the increase in the percent of filler content leads to increase in resilient modulus. When the filler content increases, the air voids will decrease and cause the recoverable strain to decrease; so the resilient modulus increases.

Table 10: Percentage Different of Resilient Modulus Due to Increase Asphalt Cement Content for Each Nominal Aggregate Size

ACT	Percent Increase in AC			Percent Different in resilient modulus %
	N.A.S 19mm	N.A.S 25mm	N.A.S 37.5mm	

	From	To	From	To	From	To	N.A.S 19mm	N.A.S 25mm	N.A.S 37.5mm
60-70	4.2	4.7	4.1	4.6	3.6	4.1	9.99	7.07	7.22
	4.7	5.2	4.6	5.1	4.1	4.6	11.58	8.64	8.43
	4.2	5.2	4.1	5.1	3.6	4.6	22.74	16.32	16.26
Average Percent Different in Resilient Modulus to Each N.A.S % at 0.5 % Increase in Asphalt content							10.79	7.86	7.83
40-50	4.3	4.8	4.2	4.7	3.7	4.2	11.40	6.53	9.31
	4.8	5.3	4.7	5.2	4.2	4.7	8.88	8.36	9.75
	4.3	5.3	4.2	5.2	3.7	4.7	21.29	15.44	19.98
Average Percent Different in Resilient Modulus to Each N.A.S % at 0.5 % Increase in Asphalt content							9.99	7.45	9.53
20-30	4.4	4.9	4.3	4.8	3.8	4.3	7.16	9.49	6.00
	4.9	5.4	4.8	5.3	4.3	4.8	12.78	8.03	7.54
	4.4	5.4	4.3	5.5	3.8	4.8	20.86	18.28	13.99
Average Percent Different in Resilient Modulus to Each N.A.S % at 0.5 % Increase in Asphalt content							9.97	8.76	6.77
Average Percent Different in Resilient Modulus % at 1 % Increase in Asphalt Content for each N.A.S							21.63	16.68	16.74

ACT: Asphalt cement type and AC%: Percent of asphalt cement content, N.A.S: Nominal aggregate size.

Table 11: Average Values of Resilient Modulus, MPa with Increase Percent of Filler Content for Each Nominal Aggregate Size

N.A.S 19mm		N.A.S 25mm		N.A.S 37.5mm	
Filler Content %	Average M_R MPa	Filler Content	Average M_R MPa	Filler Content	Average M_R MPa
5	8889.56	4	4402.35	3	3364.44
7	9666.93	6	4547.20	5	3516.69
9	9982.89	8	4715.64	7	3615.96

M_R: Resilient modulus, MPa.

9. Average values of resilient modulus, mpa effected of cement type (viscosity) for each nominal aggregate size

Three asphalt cement type was used in this research 60-70, 40-50 and 20-30 for each nominal aggregate size. The average value of resilient modulus versus Increase in asphalt viscosity is calculated and presented in Table 13. Table 14 explains the percentage difference of Resilient Modulus due to increase Asphalt Viscosity for each nominal aggregate size.

Table 13 shows that: the increase in asphalt viscosity leads to increase in resilient modulus. When the asphalt viscosity increases, its ability to bind the aggregates together increases too; therefore, the recoverable strain decreases, thus resulting in increasing resilient modulus.

10. Average values of resilient modulus, mpa effected by testing temperature for each nominal aggregate size effect of on resilient modulus

The average value of resilient modulus versus an increase in testing temperature is calculated and presented in Table 15. Table 16 explains the percentage difference of Resilient Modulus due to increase Test Temperature for each nominal aggregate size. The result represent that when increasing test temperature, resilient modulus decreased this may be due to the softening of asphalt cement with increase in temperature, while the softening of asphalt happens because of the permanent strains with load application and this leads to decreasing in resilient modulus. As well as viscosity of the asphalt cement decreases when the temperature increases. Thus suffer to flowing asphalt cement within throw the mix and relieve the stresses, while asphalt may collapse in its ability to bind the aggregates together at high temperature. Therefore, the recoverable strain increases as the temperature increases, thus resulting in lower resilient modulus.

11. Average values of resilient modulus, mpa effect by load duration for each nominal aggregate size

Three levels of load duration were used in this research: 50ms, 100ms, and 200ms to each tested temperature for all prepared specimens. Figure 6 illustrates the wave form of sample of result from test specimens at the properties of mix design condition and test condition:

1. Asphalt cement content: 4.8%
2. Filler content: 3%
3. Asphalt cement type: 20-30
4. Nominal aggregate size: 37.5mm
5. Passing sieve No. 4: 43.7$^{\%}$
6. Air voids: 5.13%
7. Voids in mineral aggregate: 24.81%
8. Voids filled with asphalt: 79.32%
9. Tested temperature: 40°C
10. Load duration: 200ms

The average value of resilient modulus versus increase in load duration is calculated and presented in Table 17. Table 18 explains the percentage difference of Resilient Modulus due to increase Load Duration for each nominal aggregate size.

Table 17 shows that when the load duration increases the resilient modulus decreases. That average; the asphalt mix was under high level of strain because the load was applied for long period of time. Thus will result decreasing the resilient modulus. This may explain the most damage of slow traffic on the asphalt pavement performance and the decrease of its design life. This corresponds with the fact that asphalt concrete is visco – elastic material and behaves elastically at faster loadings and behaves more viscously at slower loadings.

Table 12: Percentage Different of Resilient Modulus Due to Increase Filler Content for Each Nominal Aggregate Size

Percent Increase in Filler Content %						Percent Different in resilient modulus %		
N.A.S 19mm		N.A.S 25mm		N.A.S 37.5mm				
From	To	From	To	From	To	N.A.S 19mm	N.A.S 25mm	N.A.S 37.5mm

5	7	4	6	3	5	8.74	3.29	4.53
7	9	6	8	5	7	3.27	3.70	2.82
Average Percent Different in Resilient Modulus to N.A.S %						6.01	3.50	3.68
Average Percent Different in Resilient Modulus %						4.40		

AC%: Percent of asphalt cement content.

Table 13: Average Values of Resilient Modulus MPa with Increase Asphalt Viscosity for Each Nominal Aggregate Size

Asphalt Type	Viscosity* Pa.S.	Average M_R MPa		
		N.A.S 19mm	N.A.S 25mm	N.A.S 37.5mm
60-70	0.351	4713.14	3587.58	2937.88
40-50	0.478	6067.26	4476.36	3471.40
20-30	0.584	7610.24	5601.25	4089.84

*: Viscosity at 135˚C and M_R: Resilient modulus, MPa.

Table 14: Percent Different of Resilient Modulus Due to Increasing Asphalt Viscosity for Each Nominal Aggregate Size

Viscosity Increase Pa.s.		Percent Different in Resilient modulus %		
From	To	N.A.S 19mm	N.A.S 25mm	N.A.S 37.5mm
0.351	0.478	28.73	24.77	18.16
0.478	0.584	25.43	25.13	17.82
Average Percent Different in Resilient Modulus to Each N.A.S %		27.08	24.95	17.99

Table 15: Average Values of Resilient Modulus MPa with Increase in Test Temperature for Each Nominal Aggregate Size

T. T °C	Average M_R MPa								
	N.A.S 19mm			N.A.S 25mm			N.A.S 37.5mm		
	L.D 50	L.D100	L.D200	L.D 50	L.D100	L.D200	L.D 50	L.D100	L.D200
10	13293.22	9364.41	5703.00	9678.30	6844.96	4369.78	7123.33	5336.85	3442.41
25	8776.67	5345.37	2415.67	6471.56	4120.41	1877.78	4895.48	3206.70	1501.60
40	5769.48	2883.6	520.480	4306.89	2201.37	424.520	3468.63	1770.15	352.190

T.T: Test temperature, M_R: Resilient modulus and L.D: Load duration, ms.

Table 16: Percent Different of Resilient Modulus Due to Increase Test Temperature for Each Nominal Aggregate Size

Tested Temperature		Percent Different in Resilient Modulus %								
		N.A.S 19mm			N.A.S 25mm			N.A.S 37.5mm		
From	To	L.D 50ms	L.D 100 ms	L.D 200 ms	L.D 50 ms	L.D 100 ms	L.D 200 ms	L.D 50 ms	L.D 100 ms	L.D 200 ms
10	25	33.98	42.92	57.64	33.13	39.80	57.03	31.28	39.91	56.38
25	40	34.26	46.05	78.45	33.45	46.57	77.39	29.15	44.80	76.55
10	40	56.60	69.21	90.87	55.50	67.84	90.29	51.31	66.83	89.77
Average Percent Different in Resilient Modulus to Each N.A.S % to each 15˚C		48.88			47.90			46.34		

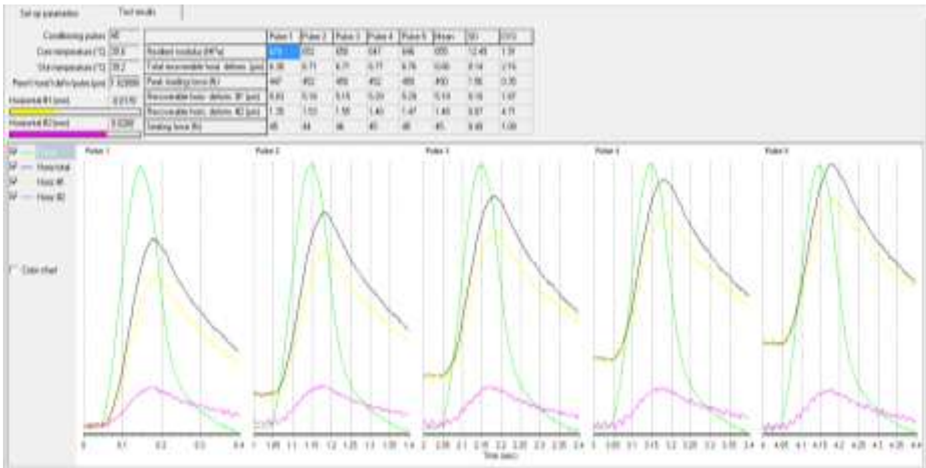

Fig.6: Output wave form as a Sample of Testing Prepared Specimens by UTM-25 Device

Table 17: Average Values of Resilient Modulus MPa with Increase Load Duration

Load Duration Ms	Average M_R MPa		
	N.A.S 19mm	N.A.S 25mm	N.A.S 37.5mm
50	9513.12	6985.58	5229.15
100	5997.79	4455.58	3504.57
200	2879.72	2224.03	1765.4

Table 18: Percent Different in of Resilient Modulus Due to Increase in Load Duration for Each Nominal Aggregate Size

Load Duration Increase, ms		Percent Different in resilient modulus %		
From	To	N.A.S 19mm	N.A.S 25mm	N.A.S 37.5mm
50	100	36.95	36.22	32.98

100	200	51.99	50.08	49.63
Average Percent Different in Resilient Modulus to Each N.A.S %		44.47	43.15	41.30

12. Conclusions

On the basis of the research findings, the following conclusions are drawn:

1. Increasing the percent of asphalt cement content of 1% will cause the resilient modulus increase up to about 21.63%, 16.68 % and 16.74 % for 19mm, 25mm and 37.5mm nominal aggregate size respectively.
2. Increasing the percent of filler content of 2% will cause the resilient modulus increase up to about 6.01%, 3.50% and 3.68 % for 19mm, 25mm and 37.5mm nominal aggregate size respectively.
3. Increasing viscosity of asphalt cement (change one grade of penetration) will cause the resilient modulus increase up to about 27.08 %, 24.95 %, and 17.99% for 19mm, 25mm and 37.5mm nominal aggregate size respectively.
4. Increasing test temperature of 15°C will cause the resilient modulus decrease to about 48.88 %, 47.90 % and 46. 34 % for 19mm, 25mm and 37.5mm nominal aggregate size respectively.
5. Increasing load duration to double value will cause the resilient modulus decrease to about 44.47 %, 43.15% and 41.3% for 19mm, 25mm and 37.5mm nominal aggregate size respectively.
6. Resilient modulus decreased by (19.64% – 23.77%) when the nominal aggregate size increased from 19 mm to 25 mm while it decreased by (21.04% - 26.66%) when the nominal aggregate size increased from 25 mm to 37.5 mm.

References

[1] Monismith, C. L., " *Influence of Shape, Size, and Surface Texture on the Stiffness and Fatigue Response of Asphalt Mixtures*, " Highway Research Board Special Report No. 109, pp. 4-11, 1970.

[2] Brown, E.R. and C.E. Bassett, " *Effects of maximum aggregate size on rutting potential and other properties of asphalt-aggregate mixtures*", Transportation Research Record, 1259, pp. 107-119, 1990.

[3] Lim, C. T., S. A. Tan and T. F. Fwa. " *Specimen Size Effects on the Diametrical Mechanical Testing of Cylindrical Asphalt Mixes* ". Journal of Testing and Evaluation (JTE) Vol. 23, pp. 436-441, 1995.

[4] Tongyan, P., E. Tutumluer, and S. Carpenter, " *Effect of coarse aggregate morphology on the resilient modulus of hot-mix asphalt* ", Journal of Transportation Research Record, 1929, pp. 1-9 , 2005.

[5] Erol T., T. Pan, S.H. Carpente , " *Investigation of Aggregate Shape Effects on Hot Mix Performance Using An Image Analysis Approach* "A final study report on the Transportation Pooled Fund Study TPF-5 (023) Prepared for the Federal Highway Administration, 2005.

[6] James C. and T. H. Kathleen " *Development of Modulus – to – Temperature Relations for HMA Mixtures Used in Wisconsin* ‘‘, Department of Civil & Environmental Engineering , Michigan Technological University, Final Report WI 53201-1881, NO. 0092-03-14, September, 2005.

[7] Algibury, T." *Prediction of Resilient Modulus in Asphalt Paving Mixture* ", M.Sc. Thesis, Civil Engineering , University of Babylon, 2008.

[8] Ghaarpour S. J. and A. Khodaii. " *Comparing Factors Affecting Resilient Modulus in Asphalt Mixtures* " Transaction A: Civil Engineering ,Vol. 16, No. 5, pp. 367-375c , October 2009.